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## **High fidelity measurement of room temperature creep in NW alloys**

### **2015 Enhanced Surveillance Annual Report**

**Lisa Deibler, John Laing**

*Sandia National Laboratories*

*Albuquerque, NM 87185*

### **Abstract**

The objective of this work was to assemble instrumentation to do the best resolution strain measurements with available equipment over a long (goal of 3 month) period of time on 304L samples. Two creep tests were performed on 304L samples for  $10^6$  seconds and instrumented with both strain gages and extensometers. The results of the test show the difficulty in accurately instrumenting creep tests for long periods of time. While the data from the strain gages at  $10^6$  seconds proved to be still discernable from the background noise caused by temperature and air fluctuations and instrument noise, lower creep rates will require enhanced measurement techniques. An additional one to two orders of magnitude of elapsed time appears feasible.

### **Introduction**

At room temperature, most structural metals are thought to be mechanically stable for decades or even centuries, so long as corrosion is taken into account. Recent results at Sandia have opened our eyes to room temperature creep as a phenomenon that can occur in ALL metals and alloys. A difficulty which this work has faced is in accurately measuring room temperature creep over periods longer than approximately a week. After that time, the creep strain becomes difficult to detect via straightforward strain measurements. In order to collect useful data over a longer period of time, which can then be more accurately extrapolated to stockpile length lifetimes, more care must be taken in measuring strain. The goal of this work was to probe the capability of doing work for longer periods of time using conventional stress and strain measurement equipment.

### **Approach**

Two extended gage length round tensile bars made from 0.5 in diameter bright drawn annealed 304L bar purchased to ASTM A182 in 1988 were instrumented in series with both extensometers and strain gages. The samples were loaded in an MTS servo-hydraulic frame as pictured in Figure 1. Additionally, a free-standing, unloaded sample was clamped to stand upright as an environmental witness sample, visible at the bottom left of the test setup in Figure 1. The upper test sample was instrumented with two strain gages on opposite sides of the sample to check for any bending asymmetry in the loading, as well as a thermocouple and an extensometer. The lower sample contained one strain gage and an extensometer, and the free-standing sample contained a strain gage and a thermocouple. In addition, a third thermocouple was free floating in the air near the test setup.

The test proceeded by ramping the load up to a stress of 64 ksi over the course of 10 seconds, which is expected to be 2-3 ksi lower than the monotonic yield strength of this alloy measured at a quasistatic

rate. The samples were then held at that stress for  $10^6$  seconds, with data collected in blocks every 100,000 seconds. After initial loading, data was recorded every 10 seconds.



Figure 1: Samples loaded in series

### Results and Impacts

The data from the first 10,000 seconds is plotted in Figure 2. The figure captures most of the data that was collected, although the strain in the reference sample was left off to allow the other recorded strains to be more easily interpreted. The most important thing to note in the data is the relative stability of the strain gage data (dark blue and dark green lines) in comparison to the extensometer data (light blue and light green lines). The influence of the HVAC system in approximately the first hour of the test on both the sample temperatures and the stability of the extensometers is obvious. This has implications for further long-term (years) creep or stress relaxation testing. It must be protected from the lab environment as much as possible.

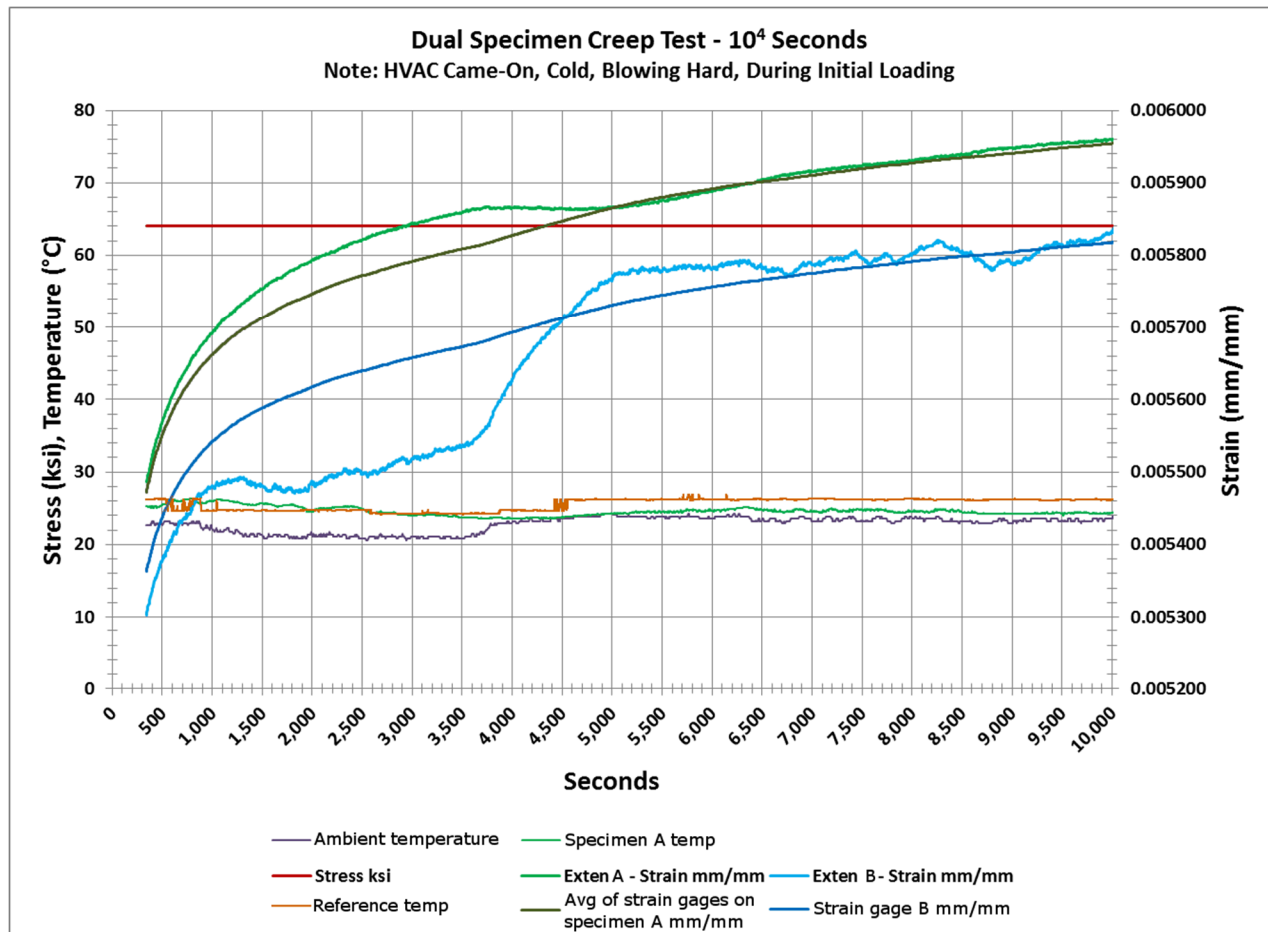


Figure 2: Creep data from the first 10,000 seconds of creep, illustrating the data that was collected and the instability of the extensometers in comparison with the strain gages.

There are several approaches which can be taken to assess the creep rate as a function of time. It has been suggested in literature and confirmed by previous work at Sandia [1] that room temperature creep can be described by a logarithmic equation. While the details of the various variables of the logarithmic type equation have not been investigated in terms of this present data, a generic logarithmic formula of the form  $\epsilon = A \ln(t) + B$  can be fit to the data to see if it fits the logarithmic form. This data has been collected in sections of 100,000 seconds each. If a logarithmic equation fits the data as a whole, the coefficients for an equation of the form of equation 1 should not vary if fit to each separate section of data.

The data was fit as shown in Figure 3 and the coefficients of the equation were recorded for each 100,000 second data set. Also note in Figure 3 the data excursions at approximately 330,000 and 355,000. These correlate to temperature fluctuations recorded by the thermocouples. The larger excursion at 355,000 seconds corresponds to an increase of approximately 3°C in the reference thermocouple above previous ambient followed by a decrease to approximately 2°C below previous ambient before stabilization.

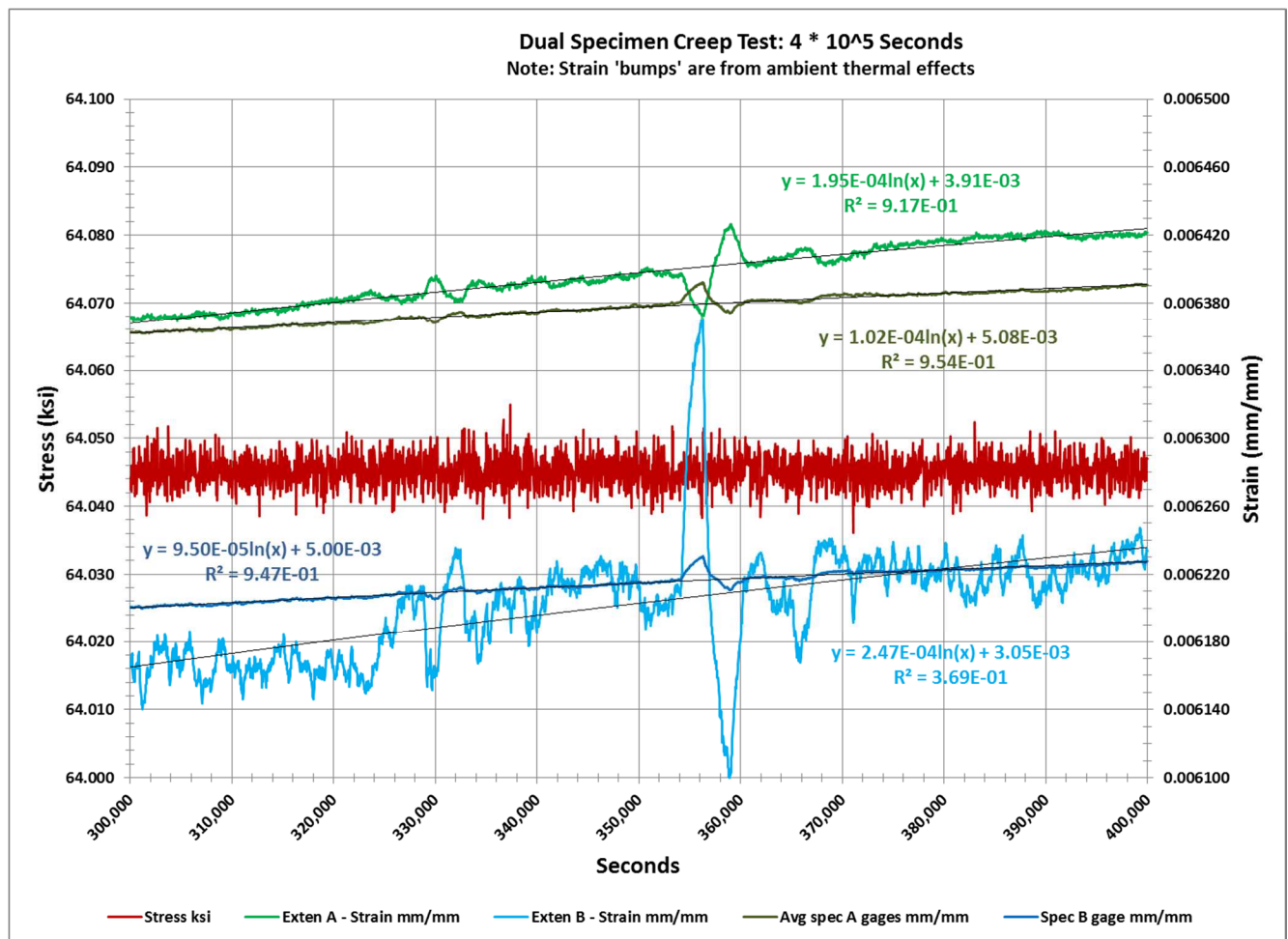


Figure 3: Data set 4 showing how the strain data was fit to logarithmic equations and illustrating strain fluctuation caused by temperature excursions.

The coefficients of the logarithmic equations for each data set as calculated from the extensometer data are plotted against time in Figure 4. It is difficult to tell purely from the coefficient data whether the coefficients are staying relatively the same or whether they are varying significantly. Certainly there is no monotonic trend in the coefficient data and it appears that the fluctuations in the coefficients increase with time. This is unsurprising because the absolute amount of creep strain that occurs with time decreases, and is likely becoming overwhelmed by noise in the system caused by other experimental variation. One way to gage how much the coefficients are changing is to calculate how much strain would be expected over a certain period of time, in this case 30 years, if creep was described by the coefficients from the first data point as compared with the last data point. If this calculation is done, the first set of data gives a strain of 0.74% in this 304L alloy after 30 years. The last set of data predicts a strain of 0.49%. This is a difference of 0.24% strain, which is an 33% difference in the predictions over 30 years.

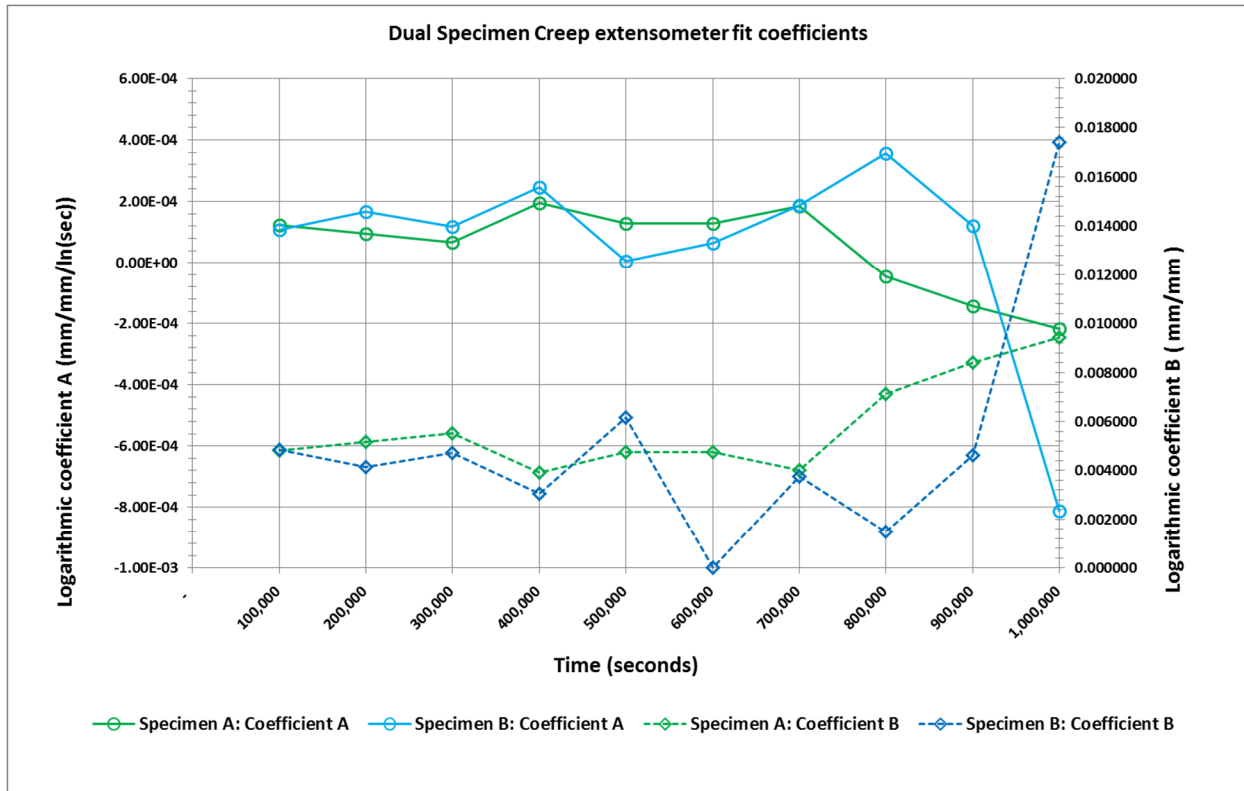


Figure 4: Coefficients from fits to data sets acquired from the extensometer readings.

In comparison, if the data from the strain gages is plotted in the same way on the same scale as in Figure 5, it appears much more stable over time. Doing the same analysis on the strain gage data shows that over 30 years the prediction from the initial data set would be 0.72% strain, while the prediction from the final data set would be 0.69%. This is a difference of 0.04% strain, a 5% difference in predictions over 30 years. This result shows two things: 1. The strain gages provide a much more stable and accurate measurement of creep strain than extensometers, and 2. The data does fit a logarithmic trend as expected.

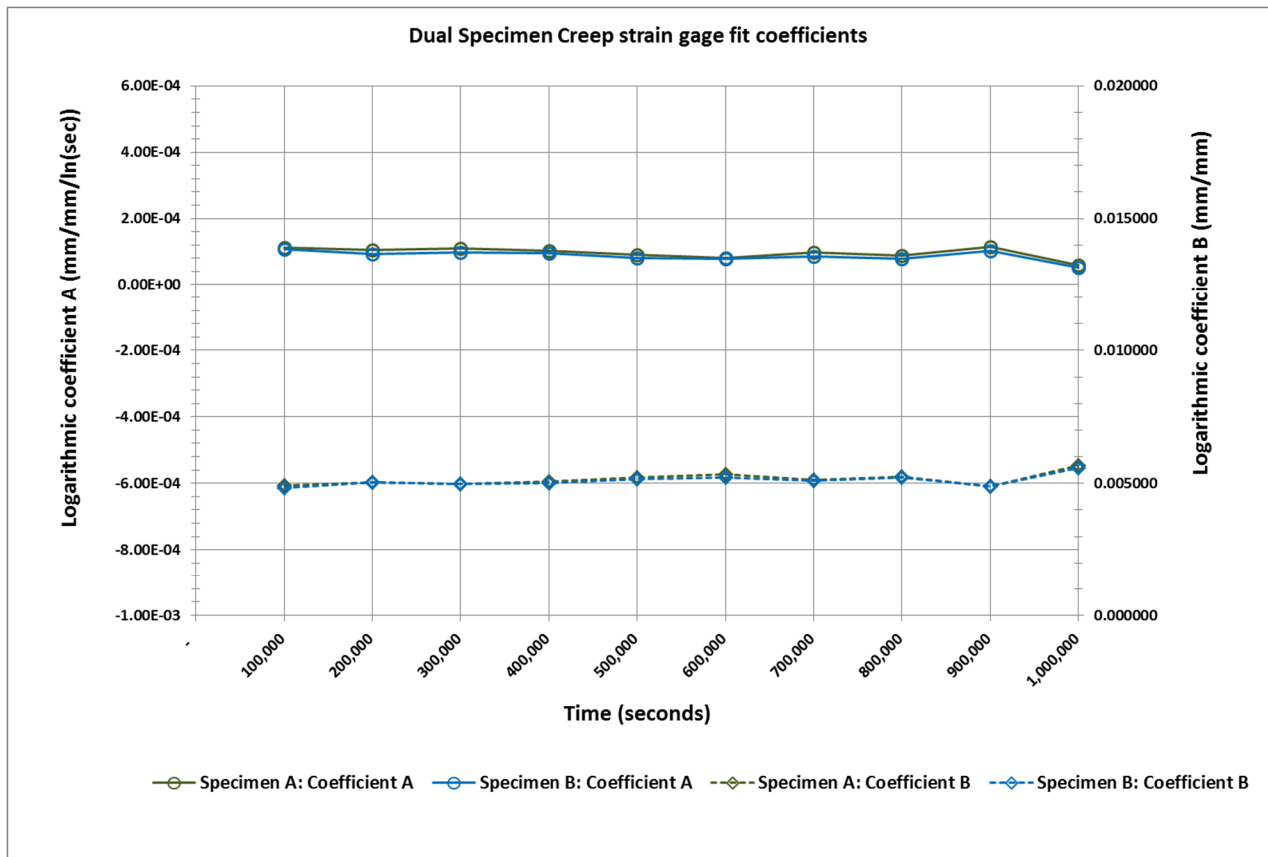


Figure 5: Logarithmic coefficients acquired from data sets generated by strain gage readings

As a check of the data, it has been compared to other creep tests done on 304L in recent years. Figure 6 is a plot of the approximate creep strain generated in creep tests done on 304L fine wire (solid lines) as well as data from a stepped creep test done a sample from the same material tested in this work (thin dashed lines) compared with the data from the test described above (thick red dashed line). This plot only contains the first 100,000 data points from this work as a comparison to the other data which has been collected. The data from this test agrees very well with the data from the creep rate jump test done on the same material with a different load frame and instrumentation, as can be seen with an amplification of the relevant data in Figure 7. The reason that the yield strength level is reported to be different in this test than in the others is that the original yield strength determination did not have the strain resolution that this test did and it was determined to be slightly higher.

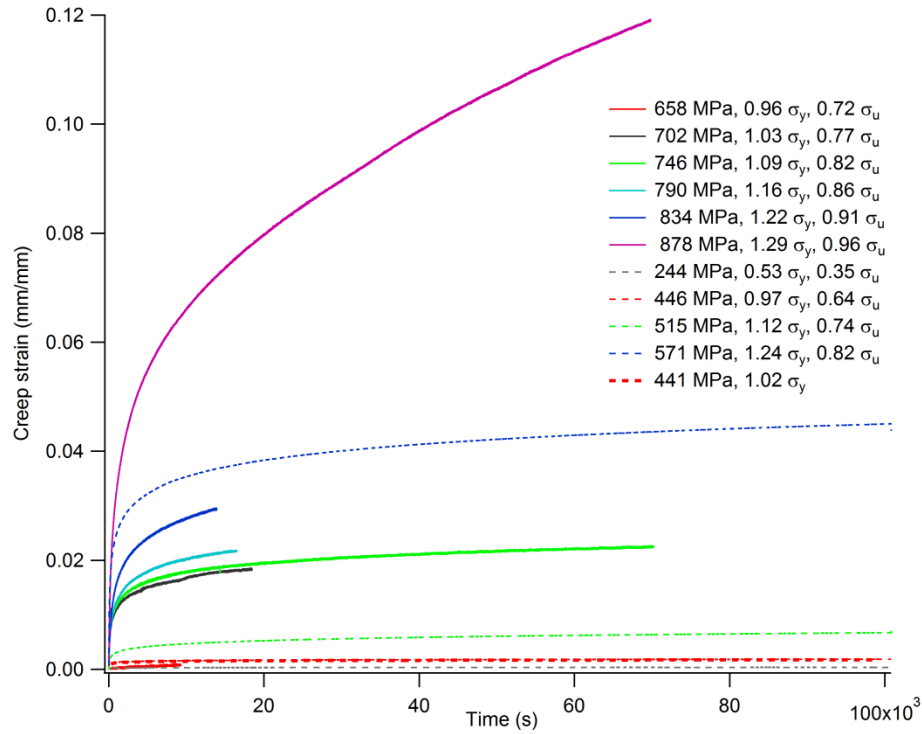


Figure 6: Creep strain results for creep level jump tests on 304L fine wire (solid lines), 304L bar tested in this experiment (dotted lines), and this experiment (thick dotted red line).

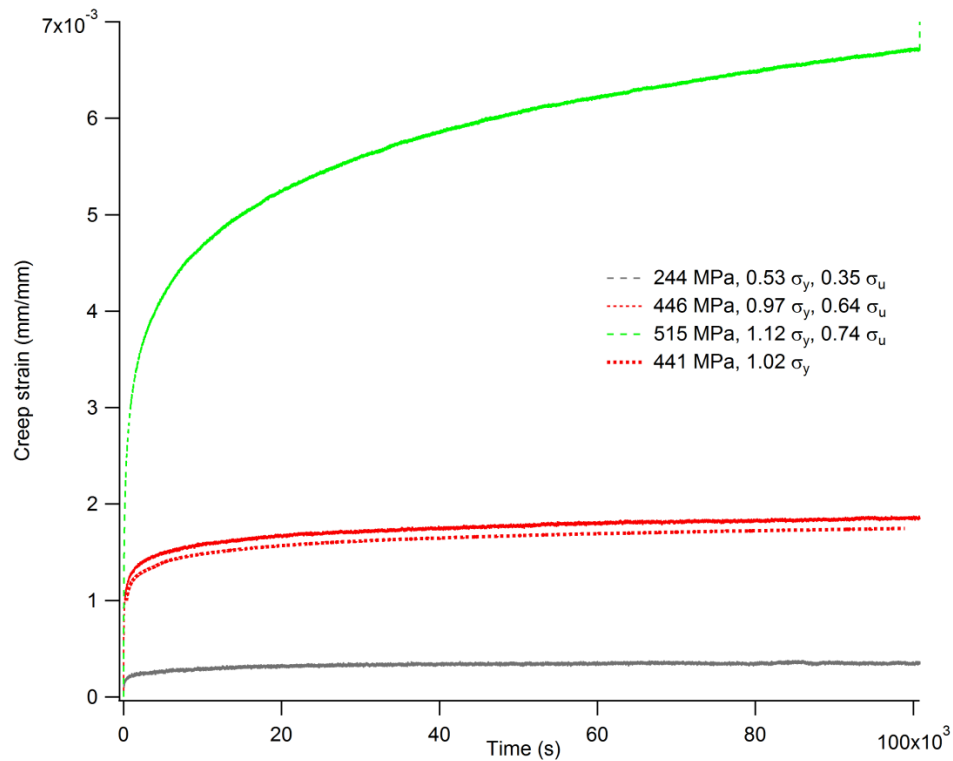


Figure 7: Comparison of data from this experiment (thick dotted red line) with data on same material from previous tests showing excellent agreement.

Another conclusion can be drawn from comparing this work to the cold worked wire work. At similar fractions of yield or ultimate strength, the cold worked wire creeps much more than this annealed bar. According to the Orowan-Nabarro equation fit to the cold worked wire data in [1], the cold worked wire would creep 4.42% compared with the 0.72% total strain predicted in this material over 30 years. This illustrates the need to investigate materials that are in the same metallurgical condition as components will be during use order to make useful predictions about creep rates.

### **Conclusions and Future Work**

Creep over long periods of time can be challenging to measure accurately due to environmental noise. This work illustrates the importance of careful experimental setup for long term creep or stress relaxation experiments. Future work on stress relaxation in spring materials due to start in FY16 will utilize many lessons learned from this work in experimental design.

Creep rates are highly influenced by the microstructural condition of the material in question, at least in the 304L investigated in this work. For future work, care must be taken to obtain test sample material which is comparable to the component material in question.

### **Summary of Findings and Capabilities Related to Aging**

- Creep rates in material with nominally the same composition can be dramatically different depending on the condition (heat treat, temper, strain level, etc) of the material. This finding will be important when applying experimental creep results to components.

### **References**

Lisa Deibler, *Room temperature creep in metals and alloys*, SAND 2014-17935

## **Administrative Addendum**

### **Related Publications and Presentations:**

Lisa Deibler. *The effect of hydrogen on room temperature creep of 304L stainless steel wire*. 10-6-14. Rio Grande Symposium on Advanced Materials. Albuquerque, NM

Lisa Deibler. *Creep at near room temperature in structural metals*. 12-11-14. 1800 Material Science Seminar

### **Milestone Status:**

Build 3 month accurate creep setup. (Q1) – complete

Collect aging data three month creep of 304L (Q2-Q4). – data was collected for  $10^6$  seconds, the same order of magnitude as 3 months.

Fit collected data to existing models. – partially complete